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Architecture of a Satellite-Based Sensor Network for Environmental Observation

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Introduction

- Sensor webs enable on demand, adaptive sensing across a wide range of spatial and temporal scales from both in-situ and space-based sensors
- Broad vision: enable wide adoption of sensor web technology in scientific research
- In-situ sensing networks are important components of large-scale sensor webs (focus of this paper)
- Explore opportunities of combined in-situ sensing and space-based sensing (future direction)

Challenges in Building Sensor Nets for Science

- Rapidly deployable in remote locations by individual scientists
- Flexible to support different science applications
- Robust to harsh environments and potential failures
- Intuitive user interfaces and tools for scientists

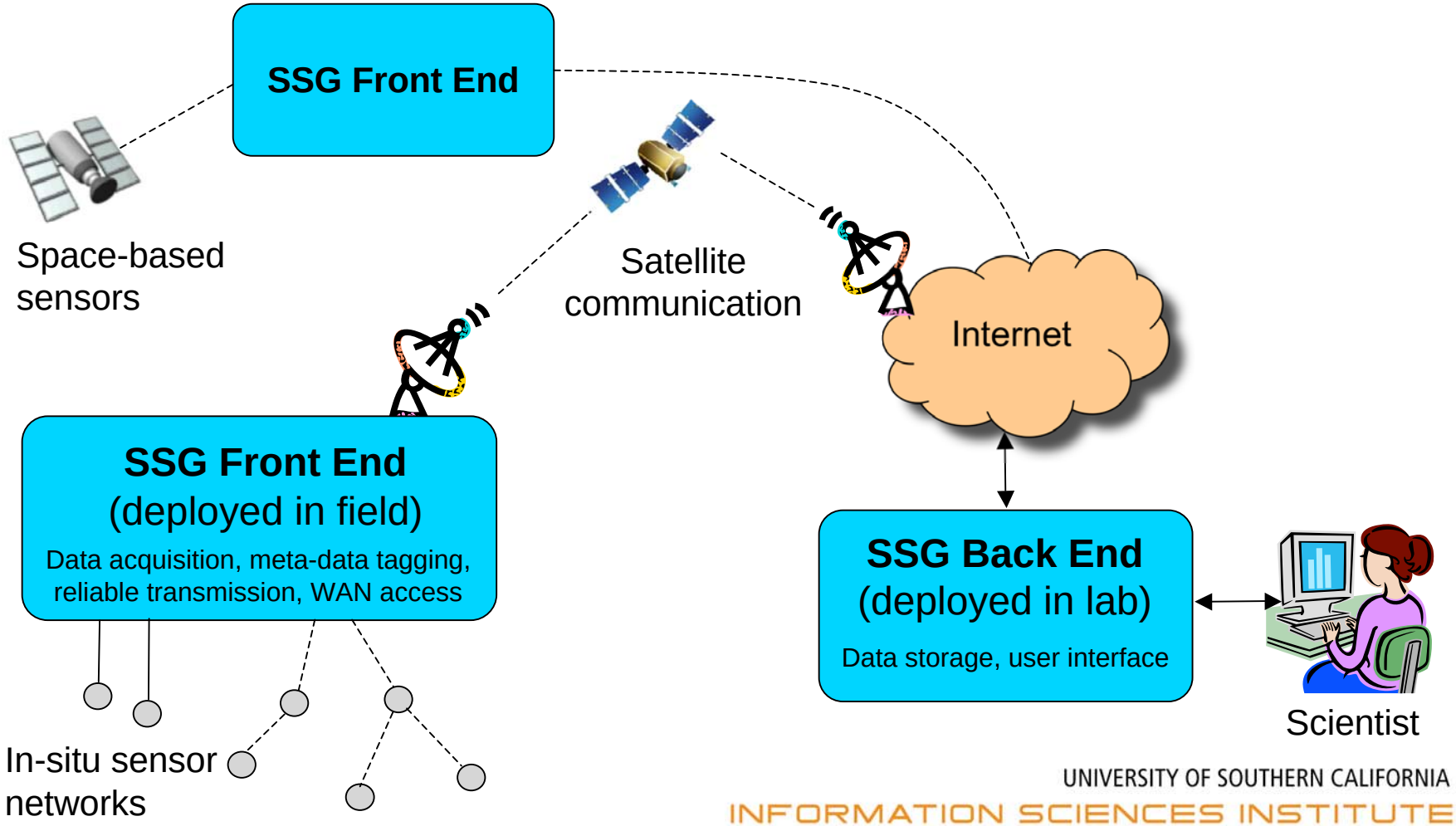
Our Approaches

- **Develop a turn-key system that addresses above challenges, called Sensor Processing and Acquisition Network (SPAN)**
  - Emphasize on modular and extensible design
- **How to address those challenges?**
  - *Remote locations:* use satellite communication (or cellular)
  - *Different science apps:* develop a unified sensor integration framework
  - *Robust operation:* extensive system monitoring and failure recovery
  - *User support:* intuitive interfaces and tools to monitor and reconfigure the system

Outline

- Introduction
- System architecture
- Prototype implementation
- Lessons learned from initial deployment
- Conclusions

High-Level SPAN Architecture



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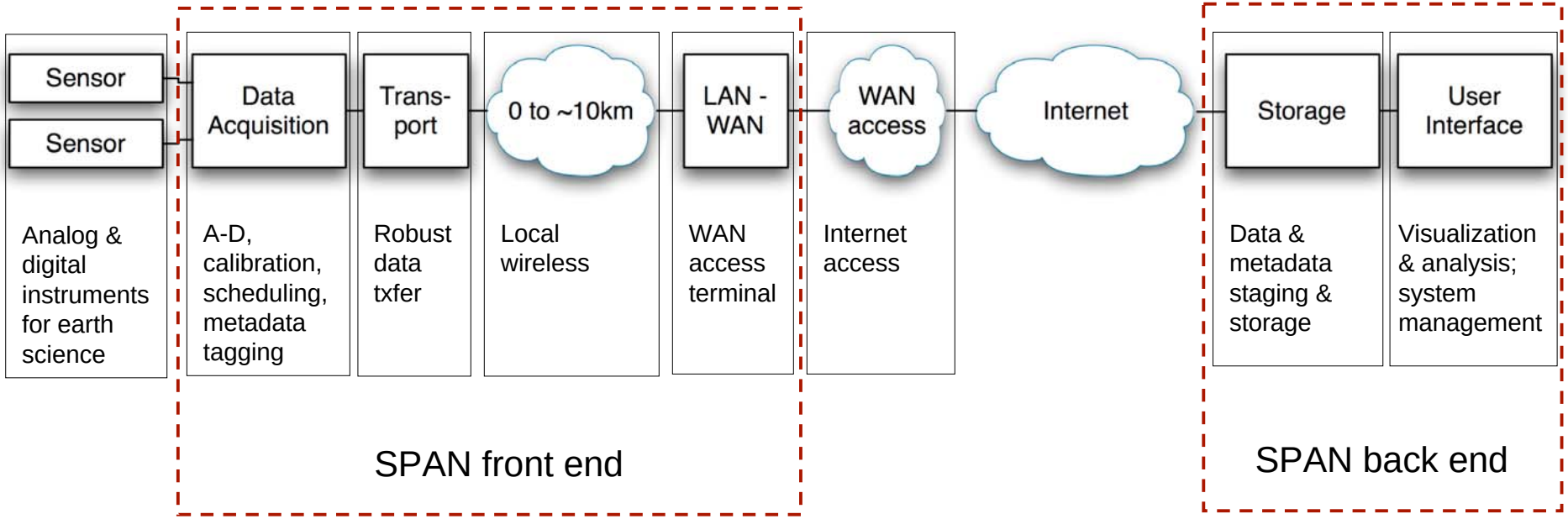
Major Functions in SPAN



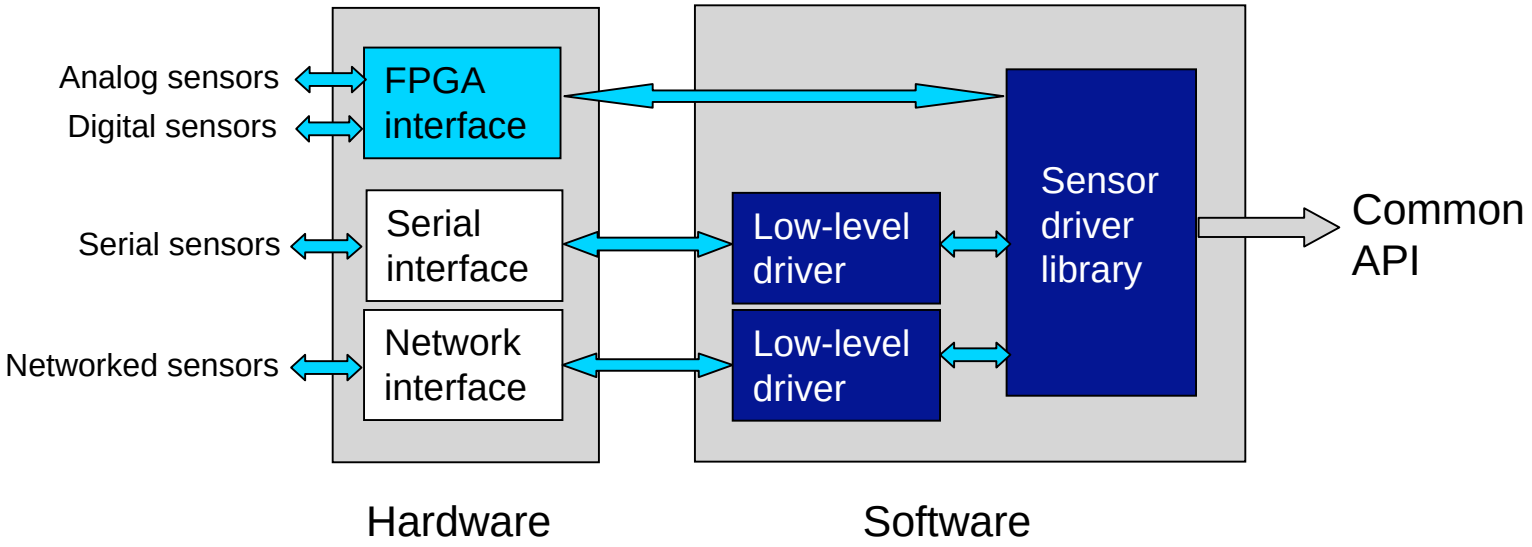
SPAN Front End (in the Field)

- ***Sensor Management***
- **Data Acquisition**
- ***Data and metadata management***
- **Reliable data transmission**
- **WAN access**

Unified Sensor Integration Framework

❖ Framework for easy sensor integration

- Simple, low-level hardware to interface with various sensors
- Modularized and extensible driver library

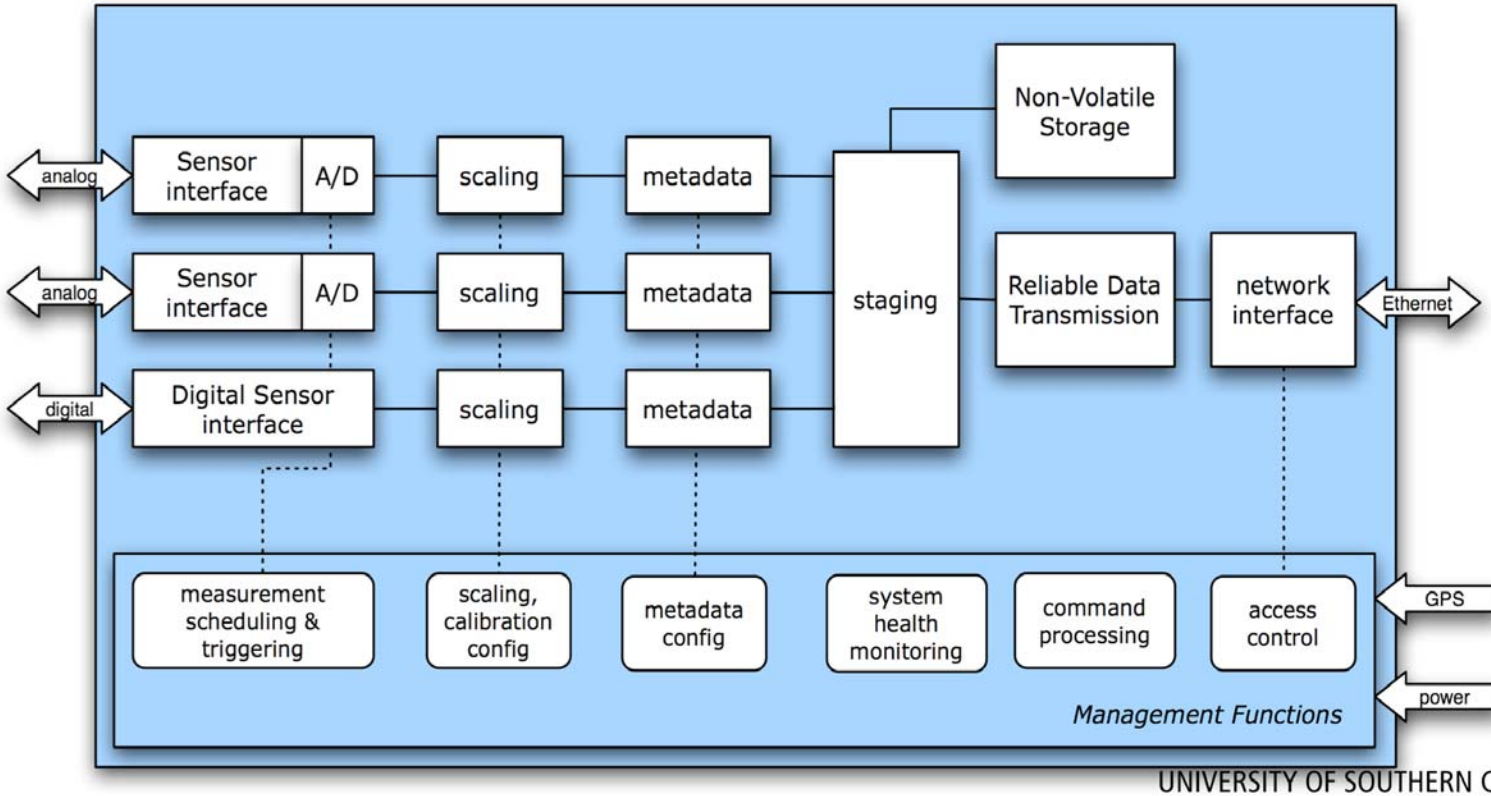


Sensor Driver Library

- **Streamlined sensor integration**
  - Mapping different sensors into system
  - Support analog, digital, serial, networked sensors
- **Software abstraction to easily control sensors**
  - Unified API to control different sensors
    - Enable or disable channels, set sampling rate, raw data or average
  - Obtain metadata for each channel
    - Sensor make, model, serial number, measurement type and unit, etc.
  - Sensor calibration
- **Modular and reusable software components**

Protocols for Data and System Management

- Designed protocols for managing data, control and status information
- Implemented protocols on CompactRIO

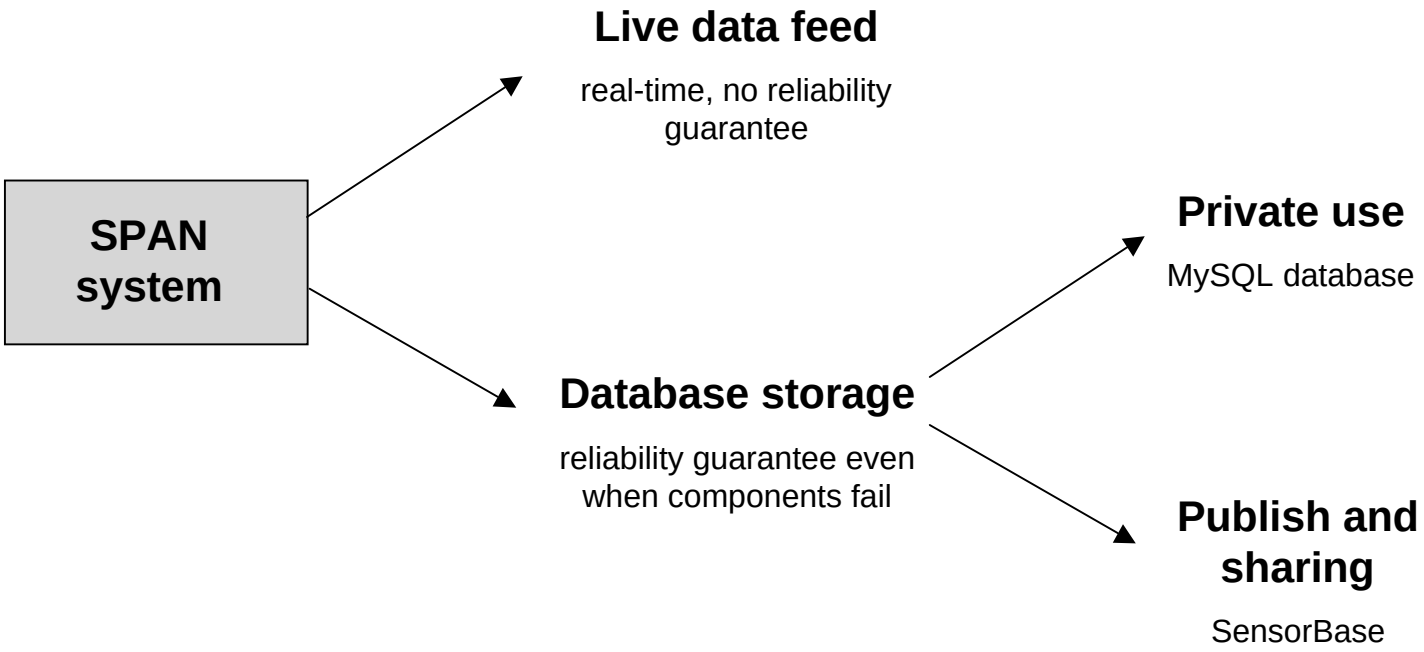


SPAN Back End (in the Lab)

- **Data storage**
  - Support both databases for individual scientists or shared by community
- **Provide three types of user interfaces**
  - **Command interface:** control and reconfigure system remotely
    - Start or stop a sensor, or change sampling rates
  - **Data interface:** easily access sensor data and metadata
  - **Status interface:** monitoring status of entire system
    - Component failure, availability of satellite link

Provide Different Methods to Access Sensor Data

- **Different access methods meet different needs**



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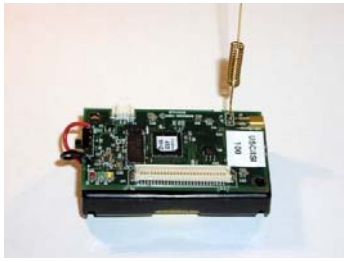
Platform Consideration

- **Data acquisition system: CompactRIO**
  - Rugged platform, rich sensor interfaces, LabView programming
- **Communication technologies**
  - WAN: WildBlue satellite-based Internet service
  - Local wireless: mote-based wireless sensor network
- **Embedded PC: Stargate**
  - Drives satellite modem and provides access control
- **Database: MySQL database**
  - Robust open-source database on Linux
- **Network monitoring tools: Nagios**
  - Nice graphical interface

CompactRIO



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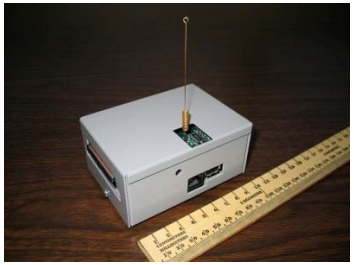
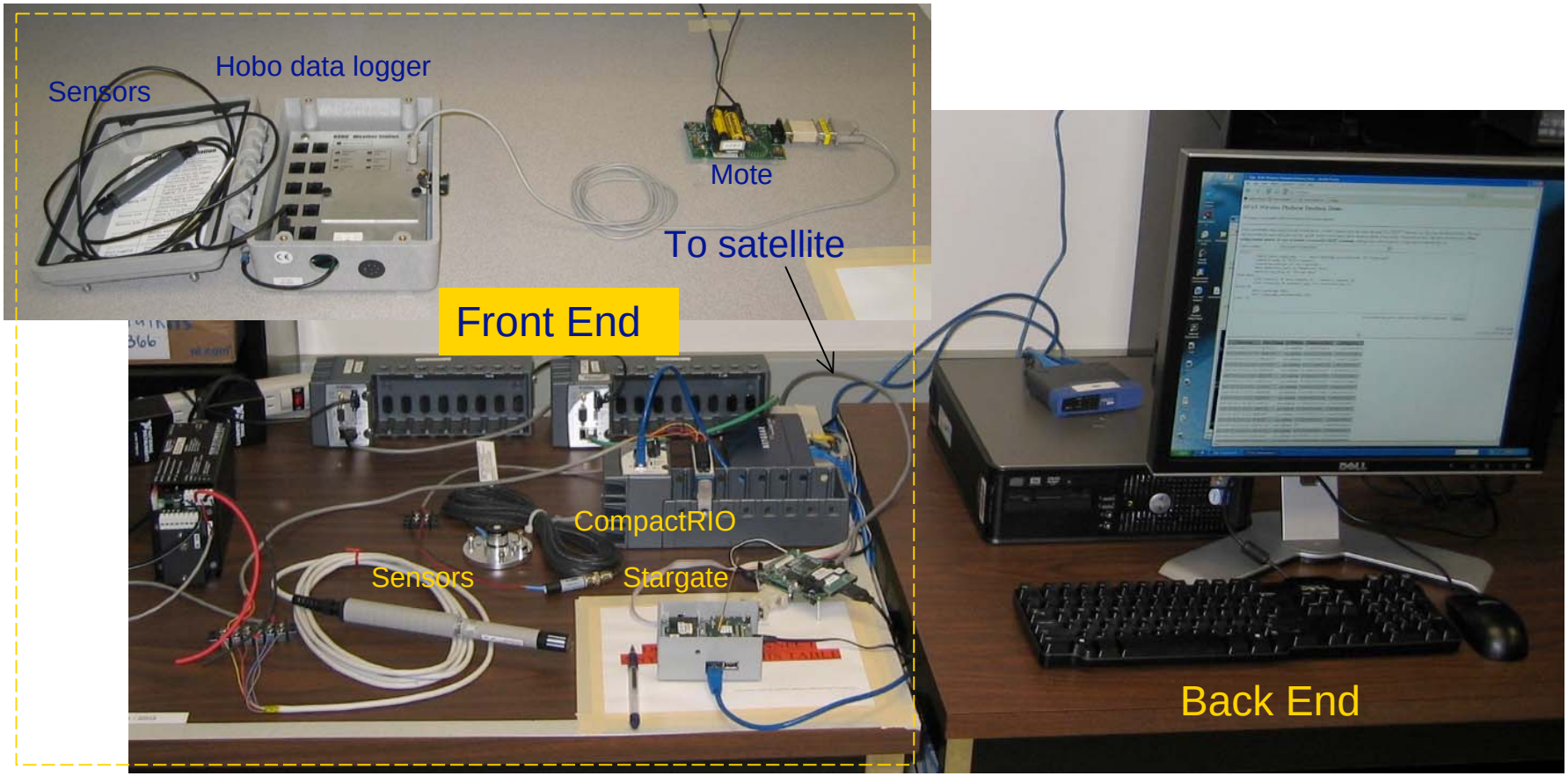


Stargate

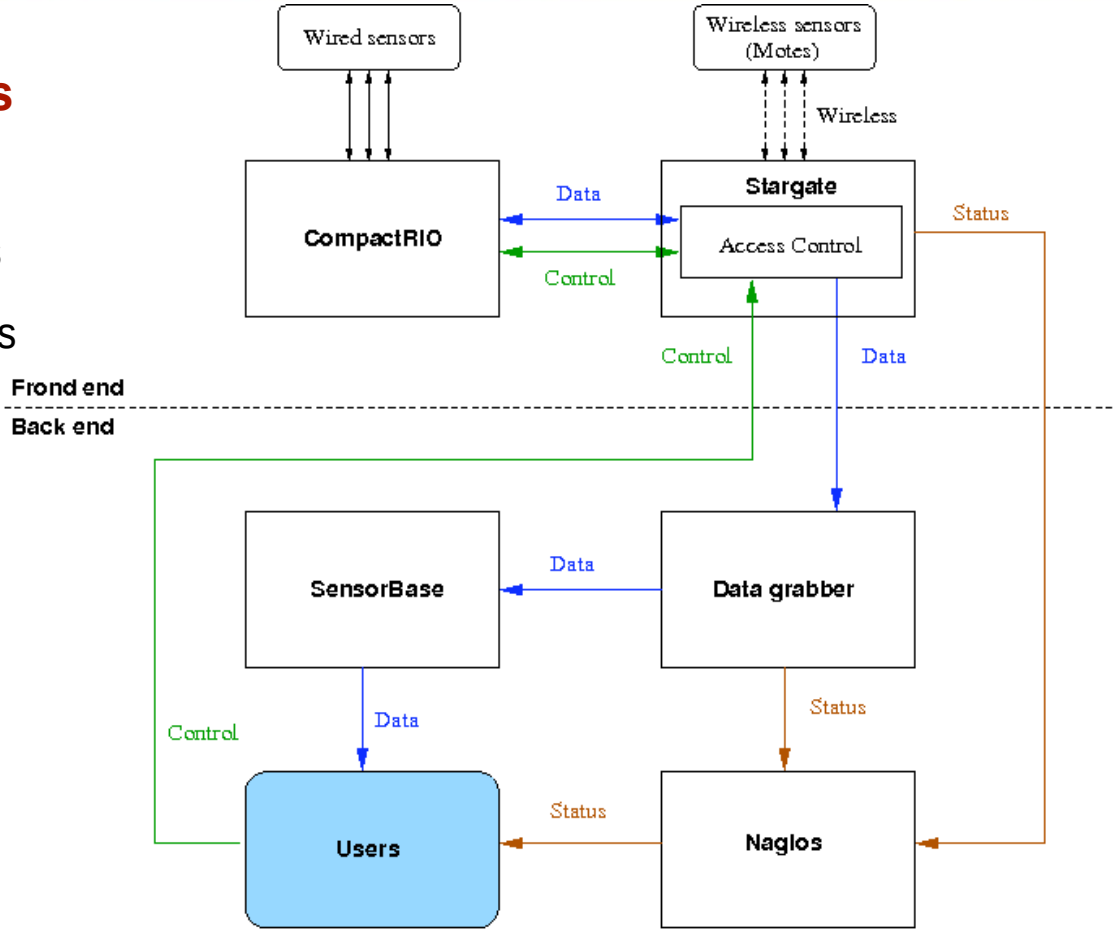
System Integration



Block Diagram of the Integrated System

Major system components

- CompacRIO: connects to wired environmental sensors
- Stargate (Linux PC): provides access control and connects to wireless sensors
- Data grabber: reliable data retrieval from front end and injection into database
- SensorBase: Database for scientists
- Nagios: system monitoring



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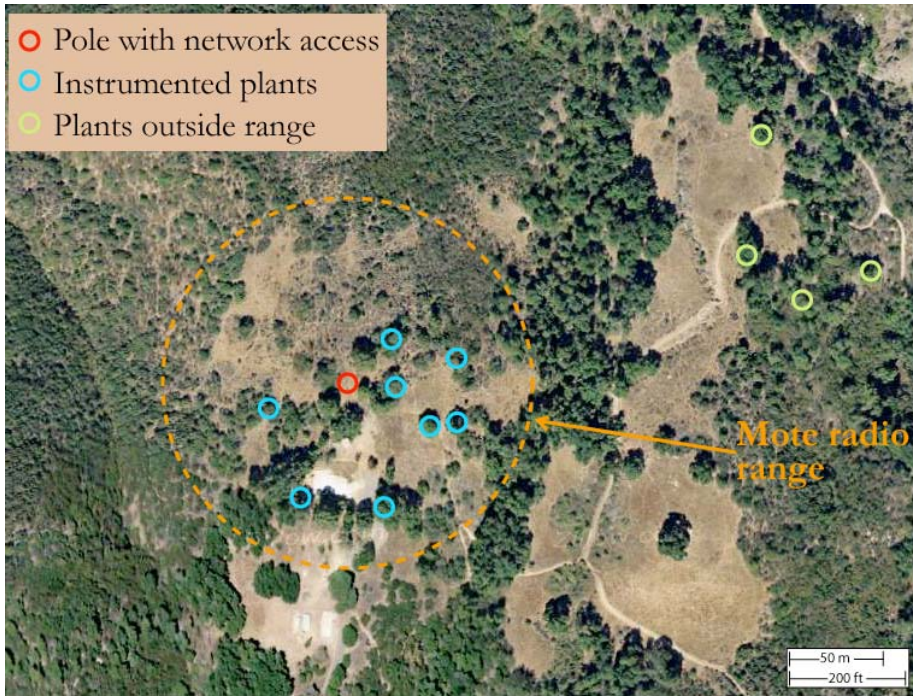
Scientific Application at Stunt Ranch

❖ Ecological research

- **Investigate the influence of southern California drought conditions on different species of plants**
- **Use constant-heating *sap flow sensors* to monitor the flow of water through the xylem of replicated stems of plants**
- **Scientist: Prof. Phil Rundel at UCLA**



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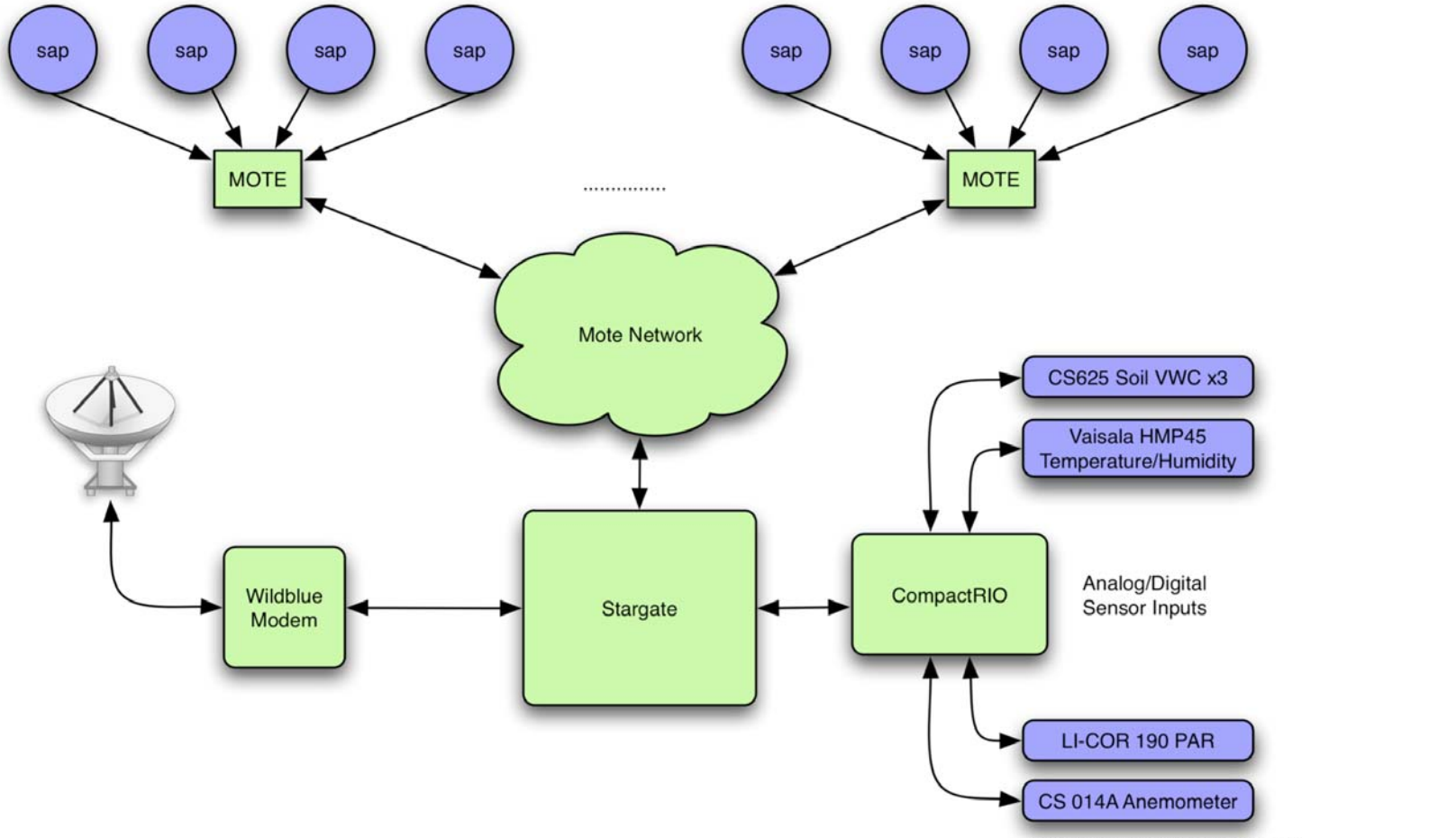
Front-End System



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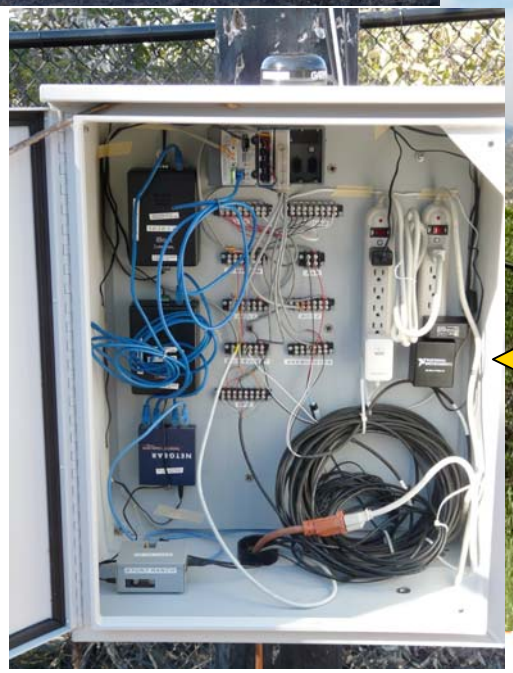
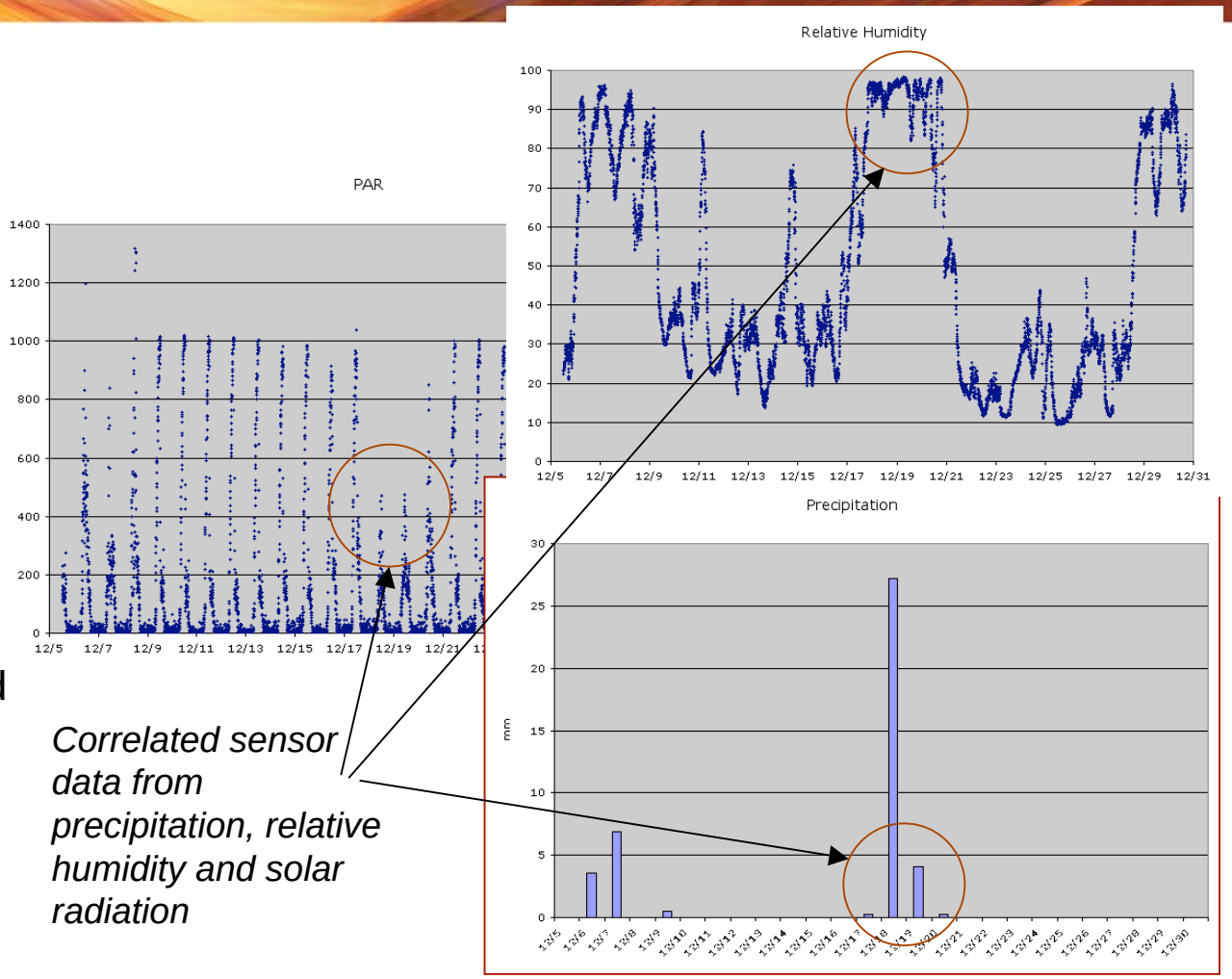
Deployment at Stunt Ranch

- **Complete front-end sysem**
  - CompactRIO
  - Stargate
  - Environmental sensors
    - Solar radiation (PAR)
    - Precipitation
    - Wind speed
    - Temperature
    - Humidity
- **WildBlue satellite comm**
- **Sap flow sensors on selected plants**



Initial Sensor Data Collection

- **Provided sensor data to scientists**
- **System operates reliably during first three months**
  - No system crash
  - No data loss
  - Discovered and fixed a few bugs for second round of deployment



Correlated sensor data from precipitation, relative humidity and solar radiation

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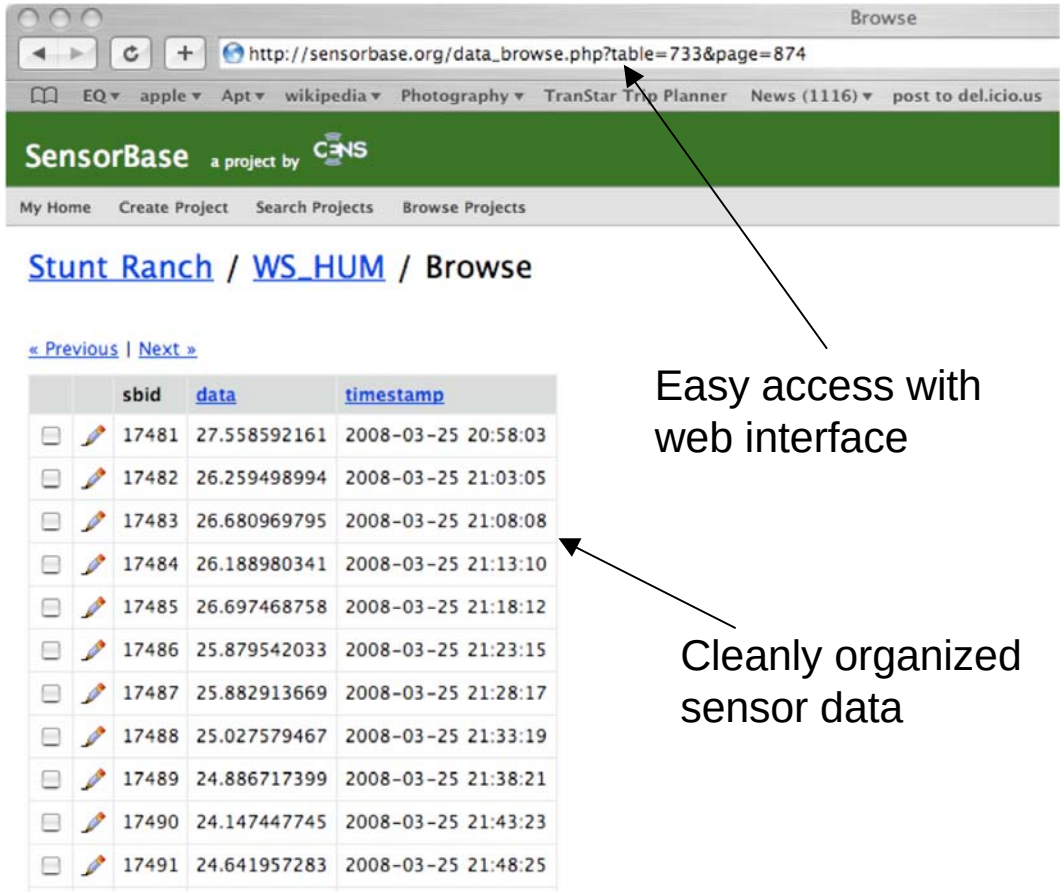
Real-Time Data Access

- **Real-time data access in SensorBase**
  - Provide real-time to scientists with database access
  - Can be shared among different scientists



Other Lessons Learned

- **Even the site has line power, cannot assume it is reliable**
  - We saw several instances that the power was cut due to unknown reasons
  - Needs backup battery to report emergency events
- **Protect the equipment from honeybees (and other insects)**
  - We found *a honeybee hive with hundreds of bees* inside our equipment box after a few months of deployment
  - Needs better sealing

Conclusion

- **Sensor webs can be a powerful technology for environmental and ecological research**
  - Combine in-situ and space-based sensor systems
  - Dynamic reconfiguration
- **Our current focus is developing robust and easy-to-use in-situ sensor networks**
- **The architecture of our system has been validated with our first prototype deployment for ecological research**

Future Directions

- **Standard-based data management**
  - Had good discussion with Mike Botts on SensorML at Sensor Web PI meeting
- **Automated and distributed system reconfiguration**
  - Fast response to triggering events
- **Explore systems and applications that combine in-situ sensing with space-based remote sensing**
  - We are interested to find collaborators

Thank you! Questions?

- **Project is funded by NASA ESTO's AIST program as "Satellite Sensornet Gateway (SSG)"**
  - website: http://ssg.isi.edu